APPLICATION

FOR

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TITLE

       SYSTEM AND METHOD FOR DETERMINING NETWORK
       DISCRETE UTILIZATION

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INTERNATIONAL BUSINESS MACHINES CORPORATION

SYSTEM AND METHOD FOR DETERMINING NETWORK DISCRETE

UTILIZATION

Background of the Invention

<u>Cross References to Related Applications</u>

5   U.S. patent application Serial No. 08/_____, entitled "SYSTEM AND METHOD FOR DETERMINING NETWORK THROUGHPUT SPEED AND STREAMING UTILIZATION", assignee docket END9 2000 0102 US1 is assigned to the same assignee hereof and contains subject matter related to the subject matter of the present

10   application. The above identified patent application is incorporated herein by reference.

    This application is an improvement upon copending U.S. patent application Serial No. 09/267,843, filed 12 March 1999, by F. K. P. Klassen and R. M. Silverman, entitled

15   "SYSTEM AND METHOD FOR ANALYZING AND TUNING A COMMUNICATIONS NETWORK", and S/N 09/452,403 filed 1 Dec 1999 by K. Chan, F. K. P. Klassen, and R. M. Silverman for "System and Method for Monitoring Performance, Analyzing Capacity and

Utilization, and Planning Capacity for Networks and
Intelligent, Network Connected Processes".

Technical Field of the Invention

This invention relates to testing and analyzing a
communications network. More particularly, the invention
relates determining network discrete utilization.

Background Art

Users and managers of communications networks are
interested in the capacity, performance, reliability,
availability, topology, service level attainment, and
modeling of their networks. Currently, many separate,
incompatible, complicated, and often unsatisfactory tools
are required to perform the tasks required by network
managers.

One prior art technique provides for communication
system analysis in which sequences of pings of different
sizes are sent, transmitted in isolation from each other, in
order to determine characteristics of the network beyond

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availability of resources and "usual" response time. In

accordance with this technique, the best and mean times for

the sequences of pings of different lengths are measured,

and then the following are geometrically derived via use of

5   the test ping packet sizes and the reciprocal of the

bandwidth slope:

-       the network path's bandwidth,

-       the network path's propagation delay, and

-       the network path's queuing time.

10   Further network testing involves sending bursts of pings to

determine the loss rate of packets, from which the "internal

packet size of the network" can then be determined. By this

it is meant that the minimum device buffer size in the

transmission path of the network can be discovered. The

15   sending of bursts of pings of decreasing size is also

described, the intent of which is to determine if smaller

packets are prioritized over larger packets. In this way,

the following is determined:

-       the network path's minimum buffer size (also

20   referred to as "internal packet size'); and

-    the network's short frame prioritization

capability.

It is recognized in the art that there will generally

be a plurality of network hops between the test station and

5   the remote station, each with its own bandwidth. In these

circumstances, taking the reciprocal of the slope of the

line representing bandwidth is equivalent to saying that:

(1 / Bandwidth) = (1 / b1 + 1 / b2 + ... 1 / bn)

where b1, b2, ...bn are the bandwidths of all the hops in

10   the path. This will produce a bandwidth close to accurate

only if there is one hop in the path that is significantly

slower than all the others. Where this is not the case, the

estimate may be inaccurate because no account is taken of

the fact that for a multi-hop path, the intermediate nodes

15   will delay onward transmission of a packet until the whole

packet has been received.

US Patent Applications S/N 09/267,843 filed 12 Aug 1999

by F. K. P. Klassen and R. M. Silverman for System and

Method for Analyzing and Tuning a Communications Network

20   (Klassen and Silverman), and S/N 09/452,403 filed 1 Dec 1999

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by K. Chan, F. K. P. Klassen, and R. M. Silverman for System

and Method for Monitoring Performance, Analyzing Capacity

and Utilization, and Planning Capacity for Networks and

Intelligent, Network Connected Processes (Chan, Klassen and

5   Silverman) improved upon the then existing art by:

distinguishing between and calculating the values for

the streaming and discrete speeds of the network; and

calculating the utilization of that connection.

The distinction between the discrete and streaming speeds of

10   a network allows for two accurate measures of network speed

across multiple hops, as opposed to the previously known

one, potentially inaccurate measure.

The discrete speed reflects the network's maximum

bandwidth for handling "conversational" type transaction

15   traffic, such as query-response.   The streaming speed

reflects the network's maximum speed for "batch" type

traffic, such as file transfers and print.   The network's

streaming speed can also be referred to as "network

throughput bandwidth."

Thus, probative test packets are transmitted, received and time stamped, and then mathematically analyzed. The result is a system and method in which full network capacity analysis can be performed across networks of any size, including the Internet, and to do so with no need for network documentation or knowledge of network topology or knowledge of capacity of network components.

It is an object of the invention to provide an improved system and method for determining end to end network discrete utilization, as distinguished from network streaming utilization.

It is a further object of the invention to provide an improved system and method for tuning the network.

It is a further object of the invention to provide an improved system and method for estimating the network's current performance and its future performance under changed conditions ("what-if" scenarios).

Summary of the Invention

In accordance with the invention, a system and method are provided for evaluating a communications network. A plurality of network evaluation signals, or probative test packets, are selectively sent and received through the network. Responsive to these evaluation signals, selective network evaluation parameters are determined and stored. Queueing theory analysis, responsive to these parameters, determines the response time and throughput characteristics, including discrete capacity, utilization and performance, of the network.

Other features and advantages of this invention will become apparent from the following detailed description of the presently preferred embodiment of the invention, taken in conjunction with the accompanying drawings.

Brief Description of the Drawings

Figure 1 illustrates a network with a test station attached in accordance with the preferred embodiment of the

system of invention.

Figure 2 illustrates a communications network and network evaluation system in accordance with a preferred embodiment of the system of the invention.

5   Figure 3 illustrates a representative logic flow for user input.

Figure 4 illustrates a representative response time routine in accordance with the preferred embodiment of the invention.

10   Figure 5 illustrates the logic flow of the application and network throughput routine of the preferred embodiment of the invention.

Figure 6 geometrically illustrates ping and transaction results and bandwidth, utilization, and message size
15   derivations in accordance with the preferred embodiment of the invention.

Figure 7 illustrates a spread sheet implementation of a preferred embodiment of the invention.

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Best Mode for Carrying Out the Invention

Referring to Figure 1, a communications network cloud 20 is depicted with a client station 21, a server station 25 (or they can be peer stations) and a network management station 23 connected to the cloud at its boundary. The program code embodying a preferred embodiment of the invention can reside in any one or in any combination in each of the three stations 21-25. As used herein, a networked system refers to a network 20, intelligent end stations 21, 25, and the network 20 together with its intelligent end stations 21, 25 considered as a unitary whole.

Referring to Figure 2, in accordance with the preferred embodiment of the invention, apparent network speed analysis (ANSA) application 30 executes on workstation 22 to measure, monitor, estimate, capacity plan, and tune communications network 20 with respect to target station 24. A user input device 26 and data store 28 are provided at work station 22, and ANSA 30 includes a throughput routine 34, a service

level and capacity planning routine 36, and optimized ping
and other routines 38.

Network response time analysis routine 32 provides for
determination of the apparent bandwidth, utilization,

5   internal message size, queue factor, and device latency of
communications network 20.

Throughput analysis routine 34 provides for defining,
calculating, and using the following network concepts: Hop
Count Factor, Duplex Factor, Throughput Factor, and

10   Multi-Server Factor. Routine 34 relates to the receiving
station, which as shown here may also be the sending
station. As will be more fully described hereafter, in an
exemplary embodiment, routines 38 first determine the MTU
size of the network between send station 22 and target

15   station 24, and then sends bursts of that packet size to
target station 24. Target station 24 may echo or not. If
it echos, throughput routine 34 would typically be provided
at work station 22. However, routine 34 may also be
provided at some station other than the station originating

20   the packet bursts. If target station 24 does not echo, then
it must time stamp the bursts and either do a throughput
routine itself or provide them to some other station to

perform the throughput analysis.

Routine 34 analyzes the time stamps to determine throughput speed of the network, which is the line speed, which is the inverse of slope of line (e,i) (Figure 5) and is calculated as the total bits in a burst packet divided by the time from receipt of the first bit to the last bit. Routine 34 also includes a throughput utilization routine, deriving the throughput utilization as (1 - (current available speed / maximum throughput speed)).

Service level and capacity planning routine 36, responsive to the skilled use of routines 32 and 34, provides comprehensive "what-if" network planning facilities; calculation of the increase (or change) in network traffic before network response time service level is compromised; calculation of the additional file load capacity of the network, which is the additional file load before response time is compromised (for both prioritized and non-prioritized network cases); and determination of tuning recommendations for recommended window size for file transfer to fill remaining capacity (both respective and irrespective of maintaining response time service level, and for both prioritized and non-prioritized cases). In

addition, routine 36 performs comprehensive what if end

processor planning for the end systems with respect to

processor-bound, I/O-bound, and general transactions.

Optimized ping and other methodologies routines 38

5   provides for optimized pinging, and extensions for ping,

transaction, file echoing, bursts, multi streaming, and

unidirectional transmission and recording.

Referring to Figure 3, a flow chart is depicted in

which program code or microprocessor-based microcode in a

10   management function on a user, server, peer, management, or

other device 21, 23, or 25 attaches to the network 20 and

performs a sequence consisting of probative testing and

analytical steps from which the capacity and utilization of

the entire end-to-end system and its component end processor

15   and network parts are stored, displayed, and retrieved,

thereby reflecting the past and present condition of the

networked system. Furthermore, with user input of proposed

changed conditions, the future capacity, utilization, and

performance of the networked system are calculated and

20   reported or displayed.

Referring further to Figure 3, in accordance with the

preferred embodiment of the method of the invention, in step
100 the user signs on through input device 26 to the
apparent network speed analysis application (ANSA) 30.

In step 102, the user adjusts default values, if
desired. These default values include number of short or
long pings and transactions, number of bytes per ping, and
time between pings and transactions, as well as whether
ANSA's network calculation is to be based upon a default
value for average network message length, a user input value
for average network message length, or a value that the
system calculates.

In step 106, the user enters the IP address (or name)
of the target station 24.

In step 108, the user enters the file transfer packet
size (MTU).

In step 110, the user selects any or all of hop count,
duplex, and streaming file transfer cases if throughput
analysis is desired.

In step 112, the user selects a desired interactive

(transaction response time-oriented) window recommendation routine and/or batch (file transfer) window estimation routine.

Referring to Figure 4, in accordance with a preferred embodiment of the invention, the apparent network speed analysis application (ANSA) 30 performs its response time routine 32.

In step 120, ANSA 30 sends to target station 24 over communications network 20, for example, 10 short pings of 64 bytes, 10 ms apart, unless modified in step 102 to new values.

In step 122, ANSA records the sequence numbers and round trip times for the short pings.

In step 124, ANSA sends, for example, 10 long pings of 1464 bytes, 10 ms apart, unless modified in step 102 to new values.

In step 126, ANSA records the sequence numbers and round trip times for the long pings.

In step 128, ANSA calculates, in a manner to be more fully described hereafter, response time parameters, including the following values, from the set of long and short pings: apparent bandwidth, current available bandwidth, current unavailable bandwidth, apparent utilization, apparent latency, average queue time, apparent queue depth, apparent queue factor, apparent average network message length, apparent maximum user window size, estimated current user window size, apparent jitter, estimated path propagation delay, apparent device latency, estimated optimal network service level, estimated current network service level, and estimated network utilization level at which service level compliance is compromised.

In the calculations described in Klassen & Silverman, ANSA 30 treated pings that timeout (no response received) effectively as 100% utilization events in the calculations and thus as having consumed the user specified ping timeout value. In the present invention, pings that timeout are proportionately considered to be indicators of events of over 90% utilization and thus provide the basis for determination of the network average message size and the network utilization, as will be more fully described hereafter.

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Referring to Figure 5, in accordance with a preferred

embodiment of the invention, the apparent network speed

analysis application (ANSA) 30 performs its throughput

routine 34.   Responsive to user selection of cases or

5   functions in step 110, ANSA performs any or all of the

functions in steps 130-146.

In step 130, ANSA 30 performs a unidirectional file

transfer (FTP) or stream of unidirectional (non-echoed)

bursts.

10   In step 132, ANSA 30 performs a bi-directional,

concurrent file transfer or stream of echoed bursts.

In step 134, multi-streamed unidirection bursts are

transmitted.

In step 136, all bursts are time stamped and dropped

15   packets counted.   Throughput parameters, to be more

thoroughly described hereafter, are calculated.

In step 138, ANSA 30 determines network throughput

capacity by calculating such throughput parameters as hop

count, duplex, and total throughput factors, as will be

described more fully hereafter.

In step 140, network throughput utilization is calculated, as will be more thoroughly described hereafter.

In step 142, discrete response time parameters are calculated, as will be more thoroughly described hereafter.

In step 144, network discrete response time capacity is calculated.

In step 146, discrete utilization is calculated for the network.

The system and method of the preferred embodiment of the invention combines a new network probing test frame transmission method with a new network analysis method that views an entire network as a singular entity and creates a queuing theory model for the network as a singular entity. In order to establish the historical, current, and predicted future of states of a network for all types of network traffic, including interactive, browser, batch, and realtime traffic, probative transmissions, including echoed and non-echoed packets, of like and differing lengths, of like

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and differing network priority, individually and in bursts or streams, are sent and transit times measured, and queuing theory applied to the results.

Discrete Utilization

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As is described more fully in the copending patent application S/N _____ (assignee docket END9 2000 0102 US1), when determining streaming utilization, a plurality of bursts of test packets (generally ten packets per burst) is

10   transmitted and the results analyzed.

For determination of discrete utilization a plurality of transmissions of individual packets of different lengths (in an exemplary embodiment, without loss of generality, packets of two sizes, one "short" and one "long") are

15   transmitted, each packet in isolation from the other and not in a burst. The network's discrete speed is calculated by considering the best end to end round trip time for long packets and short packets, as described in detail in Klassen and Silverman. The best time for the short packet is

20   subtracted from the best time for the long packet and the number of short packet bits is subtracted from the number of

long bits. The resulting ratio of bits divided by time determines the network's discrete speed.

The streaming speed, discrete speed, and streaming utilization of a network provide a basis for the calculation of its discrete utilization. In addition to these values, the average queue wait time for service "Tw", and the standard deviation of the average queue wait time for service "σTw" (i.e., sigma Tw) are used in the calculation of discrete utilization. These queue wait time values are calculated from the time stamped database records of the plurality of discrete test ping transmission samples by standard statistical analysis.

Referring to Figure 7, a spreadsheet example for determining network discrete utilization and average message size is presented. In Table 1, the cell formulas for the spreadsheet of Figure 7 are given.

Cells A6-A15 represent test samples from which average network queue wait time (cell A16, or Tw) and standard deviation of wait time (cell A17) are determined. There are ten samples of equal length pings, sorted by shortest first. Total times have been subtracted to derive the time delta of

arrival, best to worst.

Cell J7 stores the observed line speed, or throughput speed (bytes per second).

Cell J8 stores the observed discrete speed (bytes per second).

Cell J9 stores the two-way hope count.

Cell J10 stores the observed Tw factored for hop count (in seconds).

Cell J11 stores the observed σTw not factored for hop count.

The table of cells A25-G30 is a section or view of a larger table used, in accordance with this exemplary embodiment, for determining discrete utilization. Cells in row 25 depict values from 33%-39% (represented as decimal equivalents) for utilization. Rows 27 and 28 show the message characteristics of this network and individual hop utilizations at those network utilizations. Rows 29 and 30 show ratios. When rows 29 and 30 are equal in value (within

some error value), the corresponding column represents the utilization parameters for this network.

Cell A32 calculates discrete utilization as the average of cells F28 and F25. Column F is selected for this calculation because of best match, or the equality, of cells F29 and F30.

Cell A33 copies the value in cell J10 for Tw.

Cell A34 is the messages on queue, derived from cell A32 according to the formula in Table 1.

Cell A35 is the hop speed copied from cell J7.

Cell A36 is the network average message size, calculated according to the formula in Table 1.

TABLE 1: SPREADSHEET EXAMPLE CELL FORMULAS

CELL	FORMULA
A16:	@AVG(A6..A15)
A17:	@STD(A6..A15)
A26:	(A25/(1-A25))*2
A27:	+A26/J9
A28:	+A27/(1+A27)
A29:	+A28/(@SQRT(A28*(2-A28)))
A30:	+J10/J11
A32:	(F28+F25)/2
A33:	+J10
A34:	+A32/(1-A32)
A35:	+J7
A36:	@INT((A35/A32)*(A33-(A33*A32)))
...	(FOR CELLS B26..G30, COPY FROM A26..A30)
J9:	(J7/2)/J8
J10:	+A16/J9
J11:	+A17

Referring to chart of Figure 6 in connection with the spreadsheet of Figure 7, the Y-axis is transmission time across the network, so points a,e, and m are successively increasing times. The X-axis is number of bytes per average network message, so points a, b, c, and d are successively increasing numbers of bytes that could be the numbers of bytes of an average message in the network.

a represents the origin point, which is zero bytes, zero time.

The data points represented by triangles j through q, and k through r represent the time it takes probative test sample packets to traverse the network. This could be a one way transmission or a two way (echo packet or ping) transmission.

b is the number of bytes in each of the j through q test samples.

c is the number of bytes in each of the samples k through r.

For samples j through q, n represents the average transmission time for that set of samples, j represents the best transmission time (no queuing was experienced by this sample), and q represents the time it takes for the worst surviving packet to be received.

For samples k through r, o represents the average transmission time for that set of samples, k represents the best transmission time (no queuing was experienced by this

sample), and r represents the time it took for the worst surviving packet to be received.

In the spreadsheet of Figure 7, cells A6 through A15 represent the subtraction of the time it takes the best ping (for example, ping j in Figure 6) from each of the pings in the sequence. So for cell A6, the value is zero, because best ping minus best ping = 0. Cell A15 represents the worst ping minus the best, which on the chart is q minus j.

Cell A16 represents the average of all of the time differentials in cells A6 through A15. This value is denoted as Tw, which is the average time spent waiting on queue in the network before receiving service. On the chart, Tw is the time span represented by segment (m,e). Segments (e,l) and (m,p) are parallel, because (m,p) remains a constant distance of (m,e) from (e,l).

Spreadsheet cell A17, the standard deviation of the ping times, is known as σTw (i.e., "sigma Tw"), which is not depicted in the chart of Figure 6. What it mathematically represents is measure of the degree of variation (standard deviation) of the ping times.

Chart time (e,a) represents the latency of the network. Latency is not a factor in the calculation of utilization, and is not reflected in the spreadsheet. An approach for the calculation of latency is described in Klassen and Silverman, and is summarized hereafter.

Certain delays in transmission and receipt across the network occur that are invariant and also independent of the length of the packet being transmitted. The sum total across the network of such delays is the network's latency. The physical length of the network is always a component of latency, for network length causes propagation delay which is identical for long and short frames. Device latency will be another component of latency if and only if the device through which packets are passing can handle longer and shorter frames in the same amount of time. Communication link serialization time is dependent on packet length and is, therefore, not considered a component of latency. And because latency here is construed to consist of the invariant delays inherent in the network, network queue delay, which is variable, is also not a component of latency.

The dashed line segment (e,i) represents the streaming

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speed of the network. Herein, this speed is calculated by
transmitting a burst of (e.g., 10) packets across the
network, calculating the time from the receiver's receipt of
the first to the last, dividing the total number of bytes

5   received by the time, and multiplying by 8 to get the bits
per second throughput speed of the network. This value is
cell J7 in the spreadsheet.

Line segment (e,l) represents the discrete speed of the
network (also called "datagram speed"). As first described

10   in Klassen and Silverman, this is computed by considering
the number of bytes per small packet b from number of bytes
per large packet c and multiplying by 8 to get bits. Then
the time for transmission and receipt of j is subtracted
from the time for transmission and receipt of k to get time.

15   Bits are divided by time to get bits per second discrete
speed of the network. Discrete speed is cell J8 in the
spreadsheet.

Network discrete speed is less than network throughput
speed in a multihop network, and equal in a single hop

20   network. In this chart, speed is inversely proportional to
line slope, so discrete speed will always have equal or
greater slope than throughput speed.

Hop count, spreadsheet cell J9, represents the minimum possible number of actual physical hops in the end to end network. The hop count value is derived by dividing the throughput speed by the discrete speed. This value is then multiplied by two if the throughput speed was calculated with echo packets and the network is full duplex, which is represented the spreadsheet example. Geometrically, this calculation would be represented in the chart of Figure 6 by dividing the inverse of the slope of (e,i) by the inverse of the slope of (e,l) and multiplying the result by two.

The testing method for determining discrete line speed and discrete utilization involves transmission, receipt, and time stamping of test samples of (at least) two sizes. The geometric chart depicts samples of two sizes, namely smaller sample packets of b bytes length, and longer packets of c bytes length.

Line segment (f,j) represents the service time, Ts, for a packet of b bytes in this network. Line segment (j,n) represents the time waiting for service, Tw, for a packet of b bytes in the network. Line segment (f,n) represents the service time plus the average time, known as total queue time or Tq, for a packet of b bytes in the network. Tq = Ts

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+ Tw.

Similarly, line segment (g,k) represents the service time Ts for a packet of c bytes in this network. Line segment (k,o) represents the time waiting for service, Tw, for a packet of c bytes in the network. Line segment (g,o) represents Tq, the service time plus the average time waiting for service, for a packet of c bytes.

The total service time plus the average wait time for a packet is commonly called "total queue time," and is denoted as Tq. In the chart of Figure 6, the Tq value is represented by the perpendicular raised from segment (e,h) to segment (m,p).

Network latency, segment (e,a), is determined from samples j through q and samples k through r as follows. Samples j and k determine the slope of segment (e,l), whose inverse represents the network's discrete speed. Segment (b,j) represents the total response time for transmission and receipt of a packet of b bytes that experiences no network queuing. Therefore (b bytes * 8) / network discrete speed = Ts for b bytes, which is segment (f,j) on the chart. Subtracting Ts from total response time gives latency; that

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is, (b,j) - (f,j) = (b,f). In this example latency is

calculated from discrete speed and short packet response

time. Discrete speed and large packet response time could

similarly be used to calculate latency, as could averaged

5   large and small packet response time and size together with

discrete speed.

So far, samples j...q and k...r have been used to

determine the network's latency, discrete speed, and average

wait time. The network's actual average message size and

10   discrete utilization have not yet been calculated. These as

yet missing values are critical for purposes of capacity

planning and problem determination.

The importance of determining average network message

size can be seen as follows. If it happened to be the case

15   that network average message size were b bytes, then absent

the constant time for latency, the average network would

spend the relatively large time of (j,n) waiting on queue

for service, and the relatively small time of (f,j) actually

receiving service. When wait time is high in proportion to

20   service time, discrete utilization is high. On the other

hand, if the average message size in this network happened

to be c bytes in length, then the average wait time (k,o)

would be low in proportion to average service time (g,k), meaning that discrete utilization is relatively low. It therefore remains to be shown how to determine the network's discrete utilization and average message size from samples

5   j...q and k...r.

Without loss of generality, samples j...q are used to show the derivation of discrete utilization. Samples k...r or j...q and k...r averaged could also be used for this purpose. As shown above, (j,n) is the average wait time for

10   service, Tw, in the network. Using standard statistics, the standard deviation of the response time of samples j...q is easily calculated. Since each sample in j...q has the same value for service time and latency, which is (b,j), the standard deviation of their total response time is equal to

15   the standard deviation of their wait times, denoted as σTw. Note that if sampling is performed properly, both Tw and σTw will be equal or very close to equal for samples j...q and samples k...r. Also note that discrete utilization is denoted as p.

20

By queuing theory, Tw and σTw have the following values:

Tw = p * Ts / (1 - p)

σTw = square root (p * (2 - p)) * Ts / (1 - p).

Both Tw and σTw are easily observed and calculated from
probative samples j...q. Dividing Tw by σTw thus gives a
value that is equal to p / square root (p * (2 - p)). Since
a non-negative real number is equal to a function of a
single variable (i.e., p) which is monotone increasing for
non negative values, the solution is obtained uniquely
algebraically or by using chart values for p = 0 through
.99, which are decimal representations of 0% through 99%
utilization, to solve for p by approximation.

Once the value of p has been solved for or
approximated, the queuing theory formula n = p / (1 - p) is
used in order to determine the average number of messages on
queue, denoted by "nN". Multiplying Tw by discrete line
speed and dividing by 8 gives the total number of bytes on
queue. Dividing total number of bytes on queue by n gives
the average message size.

The average message size and utilization as calculated
above solve for the maximum possible discrete utilization,
namely the case in which the entire queue is at one hop in

the network. It is also possible to solve for the minimum

possible discrete utilization, and then provide an 'expert

system' best guess of actual maximum hop utilization by a

weighted blending of the max and min values. P represents

5   the measure of the network's discrete utilization based on

all detected queuing occurring at one hop. So P is the

maximum discrete utilization. In Figure 7, P values are

shown at cells A25-G25. "U" is the measure of the network's

discrete utilization based on the queue detected in the

10   network being spread equally over each hop in the network's

hop count. In Figure 7, U values are shown at cells A28-

G28.

Minimum possible utilization is computed as follows.

The minimum number of hops in the network is computed by

15   dividing the network's throughput speed by the network's

discrete speed. Above, the total number of messages queued

in the network was calculated. Here, that number is divided

by the hop count, which yields the average number of

messages queued per hop if messages are spread equally

20   across each hop. Utilization may then be derived using the

queuing theory formula $u = n / (n + 1)$, where u is (minimum)

discrete utilization and n is the number of messages (per

hop) awaiting and in service.

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Referring to Figures 8A and 8B, in accordance with an exemplary embodiment of the method of the invention, discrete utilization is determined by matching the observed sigma Tw value with a chart-based or calculated sigma Tw in the following manner. This process is also illustrated in the spreadsheet in Figure 7.

In step 200 several ping samples are transmitted through the network under test.

In step 202, ping sample time deltas are derived by subtracting the best ping time from each other ping time, and these may be ordered in a list.

In step 204, streaming line speed and discrete line speed are calculated, as described in copending patent application, assignee docket END9 2000 0102 US1, and in Klassen and Silverman.

In step 206, average time network waiting for service (Tw) and standard deviation of wait time (σTw) are derived from the ping samples.

In step 208, the number of virtual hops in the network

is calculated as the ratio of streaming speed to discrete
speed.

In step 210, for each utilization factor P from 0 to 1
(or some subset thereof, in increments of, say .01), the
number N of messages in the network is calculated from

$$N = P / (1-P).$$

The resulting values of N may be represented by a chart, as
in the exemplary embodiment of the spreadsheet of Figure 7,
with decimal representations of utilization listed in a row
in one percent increments. In Figure 7, a section from such
a chart, showing values of P from 33% through 39%
(represented by the decimal equivalents, .33 through .39) is
displayed at cells A25-G25. Such a chart with incremental
values other than one percent could be used, without loss of
generality. This utilization, denoted as P, represents
possible values for the end to end network utilization.

In step 210, for each utilization value P, the number
of messages N that would be in the network at that
utilization is calculated, using the standard queuing theory
formula, $N = P / (1-P)$.

In step 212, for each utilization value P, the number of messages per logical hop is calculated. This is the ratio of total messages to hop count, where hop count is calculated as the ratio of streaming speed to discrete speed.

In step 214, a utilization value U for a hop is calculated using U = N / (N+1). (Thus, P represents end to end network utilization and U represents utilization of a hop.)

In step 216, the ratio of Tw to σTw is calculated, and for each U the ratio of U to square root of (U * (2-U)). The ratio of P to the square root of (p * (2-p)) and the ratio of Tw to σTw have been determined to be equivalent for a network, for both end to end utilization P and hop utilization U.

In step 218, by comparing (that is, determining the closest match of) the network's ratio of Tw to σTw derived in step 206 with all or representative ratios of U to the square root of (U * (2-U)) for all or representative possible values of U (from 0% to 99%) the value of U for the network is determined. The example of Figure 7, this

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closest comparison occurs at cells F29 and F30.

In step 220, best, worst, and estimated actual discrete utilization values are derived. The internal hop characteristics of a network are determined by calculating the ratio of streaming speed to discrete speed. This ratio tells the minimum number of hops within the network. The utilization discovered in step 218 tells how many messages are queued in the network, but does not tell if the messages are evenly distributed throughout the network.

In this step 220, the minimum possible (best) utilization value (when messages are evenly spread throughout the network), the maximum (worst) possible utilization value (when messages are bunched at only one point in the network), and an expert system best guess of actual utilization, are derived. In the spreadsheet example of Figure 7, actual utilization is calculated at cell A32 as an average of best (cell F25) and worst (cell F28). By calculating the best and worst possible values for end to end discrete network utilization P, the upper and lower bounds for possible values of actual P are discovered.

Methods other than taking the average of the MAXU value

selected from row 25 and the MINU value selected from corresponding row 28 can be used as an expert system "best guess" for the value of P. For example, a weighted average in which a greater proportion is attributed to the upper or lower bound value may be used, or the network's streaming utilization used in determining the weighting. For example, the closer the streaming utilization is to zero, then the greater the proportion of weighting for the best guess estimate of discrete utilization P is assigned to the upper bound value for P than its lower bound.

In step 222, the average message size of the network is determined from $Ts = (Tw - (Tw*U)) / U$. Since Tw and U have been determined, this gives the value for Ts, which is the average service time per message on a hop in the network. Average message size then equals $Ts * linespeed / 8$.

The discrete utilization and the network's average message size derived in accordance with the preferred and exemplary embodiments of the invention, together with the method of using burst test sample packet transmissions for determining the network's streaming traffic rate, can be used in the "what if" calculations described in Klassen and Silverman and in Chan, Klassen and Silverman. These "what

if" calculations, using these new values, will be enhanced distinguishing discrete and streaming utilization values determined in accordance with the present invention.

5   For example, in Klassen and Silverman, a method for calculating optimum network window size was provided. That method uses the network's streaming speed, discrete speed, latency, network average message size, file transfer application average message size, and utilization as

10   required input data. In accordance with the present invention, the same basic formulas are used, but the calculations improved by (1) providing a more accurate calculation of network average message size; and (2) providing more accurate network utilizations by (a)

15   substituting discrete utilization for the prior single network utilization value in predicting the performance of the windowing mechanism acknowledgment performance, and (b) substituting streaming utilization for a singular network utilization value in determining the streaming window

20   requirements of an application.

        Thus, the "what if" calculations of Klassen and Silverman are applicable to evaluating network performance in support of different end user applications. These end

user applications are either streaming, conversational, or both streaming and conversational in nature. By distinguishing between and provides values for streaming and discrete utilization, utilization values more appropriate to end user application under examination may be used.

During the course of transmission and receipt of sample packets, there will be instances in which transmitted samples are not received by the receiver. Such frames may be permanently lost or they may be retransmitted. Whether lost or retransmitted, inherent network mechanisms, such as frame sequence numbering or network management functions enable measurement of the number of such frame losses. The method described above for utilization counts only successful transmissions in its measure of discrete utilization.

Where frame losses are encountered during the sampling period, it is necessary to account for these losses when computing discrete utilization. This is important because frame loss often occurs because heavy network utilization is causing storage buffers in the network to fill to the point that no additional incoming frames can be accepted, resulting in the discarding of frames.

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In the system and method of a preferred embodiment of
the invention, instances of frame discards are accounted for
in the following manner. Each discarded frame is considered
an instance of one hundred percent network utilization. The
successful transmissions result in a measure of discrete
utilization as described above, based on the observed ratio
of average network delay to the standard deviation of
average network delay. In order to account for dropped
frames (which have "infinite delay," and therefore cannot be
used in the calculation of the ratio), the dropped frames
are accounted for not as instances of delays but as
instances of 100 percent utilization that are averaged with
the discrete utilization measure derived from successful
transmissions.

For example, suppose a total of 100 sample frames are
transmitted and that 5 sample frames are dropped. Suppose
further that based upon the values of Tw and sigma Tw for
the 95 successful transmissions, a network discrete
utilization of 45% is determined. Since the 45% discrete
utilization value does not take the discards into
consideration, the 5 discards must also be considered. The
following formula is used to derive the complete measure of
discrete utilization (where all utilization measures are in

decimal representation of percentage):

(percent successful transmissions * discrete

utilization) + (percent drops * 1.0) = complete

measure of network utilization.

5   In the example, the calculation would be:

(.95 * .45) + (.05 * 1.0) = .4215 + .05 = .4712 =

47.12% complete discrete utilization.

Thus, this method for calculation of the value of the

10   network's discrete utilization involves the measurement of

the network's average delay waiting for service,

measurement of the network's standard deviation of delay

waiting for service, calculation of discrete utilization

from the ratio of these observed values, and then refinement

15   of that calculation by proportionate factoring in instances

of dropped samples as cases of one hundred percent

utilization to arrive at a final figure for percent of

network discrete utilization.
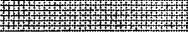
In accordance with a specific embodiment of the invention, the explicit formulas calculated by ANSA are set forth hereafter. By deriving apparent bandwidth (response time capacity), network streaming utilization, network discrete utilization, and the network message size, all of queuing theory is now available for analytic and predictive purposes and can be applied, as described in Klassen and Silverman. Network streaming speed, Average Network Streaming Speed, Network Streaming Utilization, Network Discrete Speed, Network Queue Wait Time, Standard Deviation Network Queue Wait Time, Network Queue Wait Time, "Tw," from a queueing theory perspective, are more fully described in in copending application S/N _____ (assignee docket END9 2000 0102 US1).

Network Streaming Speed (the rate at which a network is capable of streaming a user's traffic, end to end, when otherwise vacant of traffic)--

Formula:

network streaming speed = total bits in burst / total

receipt time for burst

Average Network Streaming Speed (the speed at which the

network is capable of streaming a user's traffic under

current conditions, including the traffic of other users of

the network.) --

Formula:

average network streaming speed = total bits in burst /

average total receipt time for burst

Network Streaming Utilization (the percent of the network

currently in use that is not available to a user commencing

use of an application that will stream traffic along the end

to end network connection.) --

Formula:

network streaming utilization = (network streaming

speed / average network streaming speed) * 100.

As noted above, this includes overhead incurred for
retransmissions.

Network Discrete Speed (this is the end to end rate at which
datagram traffic will be carried across the network if the
network is empty of other traffic and there is no
retransmission required.)

Formula:

network discrete speed = (long packet bits - short

packet bits) / (best long time - best short time)

Network Queue Wait Time, "Tw," as derived from testing (Tw
is the actual average wait time experienced on queues before
obtaining service between the ANSA test station and the
target station)--

Formula:

$Tw = S$ (ping sample i time - best ping sample time)

for all i / total number of ping samples.

Standard Deviation Network Queue Wait Time, σTw (the mean

statistical variation of wait times on network queues prior

to receiving service)--

Formula:

5   The standard square of the square root of the

       differences between sample times, well known in

       statistical analysis.

Network Queue Wait Time, "Tw," from a queueing theory

perspective (the queueing theory formula for Tw):

10   Formula:

       $Tw = pTs / (1-p)$

where Ts is the service time for an average network packet

and p is the network's utilization.

Standard Deviation Network Queue Wait Time, σTw, from a

15   **queueing theory perspective** (the queueing theory formula for

σTw):

Formula:

$$\sigma Tw = [\ddot{O}(p * (2 - p))] * (Ts / (1 - p))$$

where Ö denotes the square root operation.

In accordance with this embodiment of the invention, this

5   formula is used in the following derivation of the value of

a network's discrete utilization value. The importance of

this queuing theory formula is that it relates the

empirically derived value for σTw to utilization and service

time values and, therefore, provides a necessary link

10   between ANSAT testing methods and the derivation of discrete

utilization and average network message length.

Ratio for determination of discrete utilization (the key

ratio used in solving for discrete utilization)--

Ratio

15      $Tw:\sigma Tw::p:\ddot{O}(p * (2 - p))$

Formula that expresses ratio:

$$Tw / \sigma Tw = p / \ddot{O}(p * (2 - p))$$

Note:

5   The formula expresses a relationship between

utilization (the "p" variable) the network's average wait

time for service (the "Tw"). Since the Tw values are

derived by empirical sampling, this ratio and its expression

as a formula, provide the basis for the method and

10   analytical technique for using ping or other one way or echo

sampling to determine the network's end to end discrete

utilization.

Derivation of ratio and formula:

$$Tw = p* Ts / (1 - p)$$

15      $$\sigma Tw = [\ddot{O}(p * (2 - p))] * (Ts / (1 - p))$$

Dividing the top formula by the bottom, we get $Tw /$

$\sigma Tw = p / [\ddot{O}(p * (2 - p))]$.

Thus, utilization is expressed as a function of network delay.

Note:

(Ö denotes the square root operation)

5   **Network hop count** (network hop count is the minimum minimum number of network queues on the end to end path)--

Formula:

network hop count = network streaming speed / network discrete speed

10   Notes:

(1)   This invention and its immediate predecessors consider the network to be a "black box" unitary entity, and not a network of queues.   Prior to these, gathering information about the locations and characteristics of all system

15   components and their workloads was required prior to construction of the network or system model which included

network of queues analysis.

(2)   In accordance with the present invention, test packets are sent across the network (or other system) and used to deduce the capacity of the network, its latency, and the current utilization of the capacity with no foreknowledge of the systems components or their workload.

(3) It is, therefore, important to note that the "network hop count" is not a count of actual network hops. Rather, mathematically, it is a measure of the minimum number of hops of network bottleneck hop speed that could be in the actual network, which is the lowest possible total number of hops. This number is used in determining the network's minimum possible network discrete utilization, which in turn is used in a preferred embodiment of the invention by an automated "expert system" in providing a best estimate of network discrete utilization for planning, capacity analysis, tuning, and service level analysis purposes.

Number of messages on queue at a given rate of utilization (as utilization increases, the average number of items on queue awaiting service or in process increases)--

Formula:

number of items in service or being served = p / $(1-p)$.

Notes:

5   (1)   In formulas hereafter, this value is denoted as "p," and is the decimal representation of percent of overall network utilization.

Messages queued per logical hop (at a given rate of network utilization, this is the measure of messages per internal 10   hop if messages are spread equally among these logical hops) --

Formula:

messages queued per logical hop = number of items in service or being serviced / hop count.

15   Notes:

(1) Number of items in service or being served is from the prior formula, and is the measure of the total number of messages queued in the network.

(2) In formulas hereafter, this value is denoted as "u."

5

Utilization per logical hop (the utilization of a network internal hop if that hop has "n" messages on queue in service and awaiting service)

Formula:

10   utilization per logical hop = n / (n+1).

Note:

This represents the actual lower bound value for discrete utilization in the network.

Network discrete utilization (this is the expert system best

15   guess approximation of end to end discrete utilization for the network)--

Formula:

network discrete utilization = (p + u) / 2

Notes:

5   (1)   This is calculated here as the equally weighted average
of the lower and upper bound limits possible for discrete
utilization as determined by test packet sampling of the
network. Without loss of generality, one familiar with the
art could employ consideration of other factors, such as the
10   streaming utilization measure, which could be used in
reasonably assigning more weight to p and less to u or more
to u and less to p when performing the calculation for a
particular network connection at a particular time. For
example, generally, it would be reasonable to weigh p more
15   heavily in the calculation of discrete utilization if the
value for streaming utilization is low or zero.

(2)   Discrete utilization as described by the formulas above
is calculated based upon the ratio of Tw and sigma Tw. It
is calculated as a minimum value "u" and a maximum value "p"
20   and a weighted value of u and p averaged based upon
consideration only of sample packets that have been

transmitted and successfully received. To account for
dropped frames requires an additional formula:

**Network discrete utilization including dropped sample
frames:**

5   (percent successful transmissions * discrete

utilization) + (percent drops * 1.0) = network

utilization including dropped frames

Current network discrete speed (this is the network's

discrete speed as slowed by discrete utilization)

10   Formula:

current network discrete speed = network discrete speed

* (1 - network discrete utilization).

Average network message service time, "Ts "   (for discrete

15   utilization "d, " this is the hop time exclusive of any

queueing for the average network message)--

Formula:

$$Ts = (Tw - (Tw*u)) / u.$$

Average message size (for discrete utilization "d," this is the network's average message size)

5   Formula:

average network message size = Ts * streaming linespeed / 8.

In the prior art, utilization has been construed to have a singular value. In accordance with the present 10 invention, discrete utilization is distinguished from streaming utilization in multihop networks. The following new formula is both for measurement of utilization as a singular value in traditional queuing theory, which applies to single hop connections as well as a measure of discrete 15 utilization in multihop networks:

A.   sigma Tw (i.e., the standard deviation of network queue wait time) = square root of (utilization * (2-utilization)) * (average message service time / (1 -

utilization).

Relating the above formula A to the standard, well known queueing theory formula:

B.   Tw = utilization * average message service time / (1 – utilization).

These formulas A and B are placed in a ratio relationship. Dividing one of these formulas by the other (without loss of generality, formula B by the formula A) results in an equation in which the ratio of network wait time to the standard deviation of network wait time equals a formula with network (discrete) utilization as a single variable.

Advantages over the Prior Art

It is an advantage of the invention that there is provided an improved system and method for determining end to end network discrete utilization, as distinguished from network streaming utilization.

It is an advantage of the invention that there is provided an improved system and method for tuning the network.

It is an advantage of the invention that there is provided an improved system and method for estimating the network's current performance and its future performance under changed conditions ("what-if" scenarios).

Alternative Embodiments

It will be appreciated that, although specific embodiments of the invention have been described herein for purposes of illustration, various modifications may be made without departing from the spirit and scope of the invention. In particular, it is within the scope of the invention to provide a computer program product or program element, or a program storage or memory device such as a solid or fluid transmission medium, magnetic or optical wire, tape or disc, or the like, for storing signals readable by a machine, for controlling the operation of a computer according to the method of the invention and/or to

structure its components in accordance with the system of the invention.

Further, each step of the method may be executed on any general computer, such as an IBM System 390, AS/400, PC or the like and pursuant to one or more, or a part of one or more, program elements, modules or objects generated from any programming language, such as C++, Java, Pl/1, Fortran or the like. And still further, each said step, or a file or object or the like implementing each said step, may be executed by special purpose hardware or a circuit module designed for that purpose.

Accordingly, the scope of protection of this invention is limited only by the following claims and their equivalents.